Burrowing critters and burning vegetation

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Contents

We examine here a couple of concerns raised about what are allegedly unknown dangers about what goes on inside the Rocky Flats National Wildlife Refuge.

Burrowing animals bringing up radioactive soil

It is plausible that animals whose burrows extend several feet below the surface would bring up soil potentially more contaminated than soil near the surface. They have thus moved contaminated soil from deeper down to near the surface where it can be caught by wind and redistributed.

You could argue that animals that tunnel *upward* would deposit contaminated soil on the bottom of the burrow (farther from the surface) and those tunneling downward would move soil toward the surface.

The effect of this redistribution could be modeled more carefully, but this is unnecessary to reach an important conclusion: the average effect must scale as the 'areal density' of such (burrows per unit area). Panel (a) of Fig. 1 shows that there is 1 burrow per area $\ell \cdot w$. Let the 'initial' situation be a uniformly contaminated surface (radioactivity per unit area σ_{ini}), for convenience a rectangle of dimensions $L \times W$. The 'final' (post-burrowing) situation we'll assume consists of a large number N_b of burrows each of area A_b with a higher radioactivity per unit area σ_b around the burrows. So the final (post-burrowing) total radioactivity Q_f over the large rectangular region will be

$$Q_f = \sigma_{ini} \left(L \cdot W - N_b A_b \right) + \sigma_b N_b A_b.$$

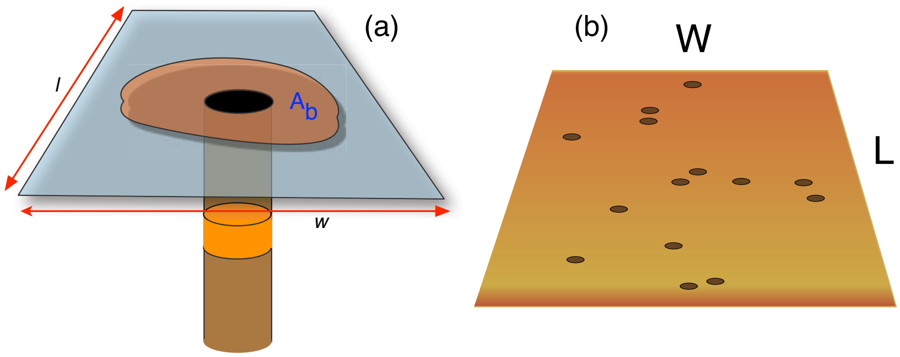

Figure 1: Schematic burrow showing redistribution of contaminated soil (orange) into above-ground area (orange-brown), panel (a). Panel (b): Schematic region with randomly-distributed burrows.

Thus we can compute the 'final' radioactivity per unit area by dividing by the large rectangle's area:

$$\begin{aligned}\sigma_{fin} &= \frac{Q_f}{L\cdot W} = \frac{\sigma_{ini}}{L\cdot W}\left(L\cdot W - N_b A_b\right) + \frac{\sigma_b}{L\cdot W} \times N_b A_b \\ &= \sigma_{ini}\left[1 - \frac{N_b A_b}{LW}\right] + \sigma_b \frac{N_b A_b}{LW} \\ &= \sigma_{ini} + \frac{N_b A_b}{L\cdot W}\left(\sigma_b - \sigma_{ini}\right)\end{aligned}$$

So sure enough, since $\sigma_b > \sigma_{ini}$, the effect of burrows is to *raise* the surface contamination, but by an amount determined by the fraction of the surface area due to burrows, the 'areal density' of burrows $N_b/(L\cdot W)$, measured say in burrows per acre or per square kilometer. A more detailed model of what goes on around the burrow itself would change the prefactor but not the fact that the *average* modification due to the burrows is proportional to this areal density, which in general will be very small provided

A physicist would just say: the fractional change would be determined by fractional change in area, a 'scaling argument'.

$$\text{(area of all burrows)/(area of wildlife preserve)} \ll 1$$

'is much less than' 1

This is the *average* effect, but indicates that only in areas with many burrows is surface radioactivity likely to be significantly increased. The issue of 'hot particles' has already been dismissed elsewhere on this web site).

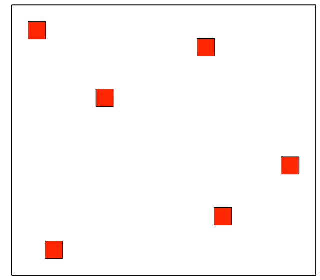

Figure 2: Rectangular region 2% covered by square 'burrows'

Scenarios

The figure in the margin shows an 'aerial view' of a rectangular area 2% covered by square 'burrows'.

To me this looks densely populated for a typical area; I would be surprised if an extended area within the Wildlife Refuge had an 'areal density' of burrows even as high as 0.1%. If this were the case, it would take $\sigma_b = 11\sigma_{ini}$ in order for the 'burrow correction' to be even a one percent correction to the 'no burrows' scenario.

It is also worth noting that prairie dogs, for example, produce large burrows, but are social animals and hence congregate into fairly dense 'towns' where the areal density of burrows is high. The CSU extension program's 2016 document 6.506 [1] discusses prairie dogs native to Colorado and indicates that the black-tailed species is the by far the most likely in areas around Rocky Flats, for example. This document states that "They live in burrows about 10 yards apart, 3 to 14 feet deep, and 10 to more than 100 feet long. A mound 3 to 10 feet across and 6 to 12 inches high at the entrance of the burrow prevents water from rushing in and serves as a lookout station. A density of 35 black-tailed prairie dog mounds per acre is common, although up to 95 mounds have been reported." We thus have the data we need to estimate the quantity $N_b A_b/(L \cdot W)$ above. Using 1 acre = 4046.9 m^2, 1 foot = 0.3048 m and assuming roughly circular burrows with a radius of (3-10)/2 feet, we find

$$\begin{aligned} \frac{N_b A_b}{L \cdot W} &\simeq (3.5 - 9.5) \times (3 - 10)^2 \times 7.3 \times 10^{-4} \\ &\simeq (0.0057 - 0.17), \end{aligned}$$

meaning that from (0.6-17)% of the area of a prairie dog town areas is occupied by burrows. Bearing in mind that these densities and sizes are appropriate to prairie dog *towns* and not average parts of the Wildlife Refuge, our guess of 0.1% for $N_b A_b/(L \cdot W)$ seems likely to be an overestimate.

It is extremely unlikely that the Fish and Wildlife Service would permit routing of hiking paths within the

Refuge anywhere near prairie dog towns, not least for the sake of the animals.

Controlled burns within the RF National Wildlife Refuge

A Google search on "controlled burn" +"Rocky Flats" returns many dozens of entries about how Boulder-based activists have managed to bully the Fish and Wildlife Service into postponing controlled burns within the Wildlife Refuge. In a *wildlife preserve* managers are thus forced to consider grazing by goats (a non-native species) or the use of pesticides as alternatives to a close approximation of what would occur naturally in the presence of lightning.

Controlled burns are also referred to as 'prescribed burns'.

[Opinion:] I can envision *no circumstances* in which a wildfire burn is preferable to a *controlled* burn, and regard it as shameful that an ostensible,'citizen's group' got away with backing the Fish and Wildlife Service into this corner.

The impact of fire on radiation exposure was considered in the 2000 report [2] to the Radionuclide Soil Action Level Oversight Panel. It states

> Including the possible occurrence of a large grass fire sometime within the required 1000-year temporal scope of the assessment. By removing vegetation from a significant fraction of the most contaminated region of the site, such a fire would enhance resuspension of soil-resident radionuclides and make them available for inhalation to people both on- and off-site.

Thus the main concern of a fire was less redistribution of Pu *per se* than of its impact on a breathable α emitter. It is worth remembering that the 'hot particle' theory, which focused on the specific dangers of particle inhalation, has not been considered viable since the mid-1970s (see the document Hot particles no longer on this web site).

Even at that time earlier versions of the RESRAD software were being used to describe the various paths by which Pu could contribute to human doses. Version 5.82 was modified to explicitly treat "the possible occurrence of a large grass fire" [2]. The authors used fire statistics for nearby national forests and the Pawnee National Grassland. Fig. 3 shows a figure drawn from the report, describing the impact on the probability of exceeding a nominal 15 mrem dose (per year) in the 'rancher scenario". (The 'Resident Rancher' scenario assumed a rancher living full time 300 m east of the '903 pad' and with all water drawn from contaminated water. This report states that "The RAC Rancher scenarios are very much in the tradition of regulatory radiological assessment practice." This report (and thus this figure) was

Reminder: 1 mrem = 0.01 mSv, so that the nominal annual dose of 15 mrem = 0.01 mSv, to be compared with an annual Colorado dose from background radiation of about 3.8 mSv per year.

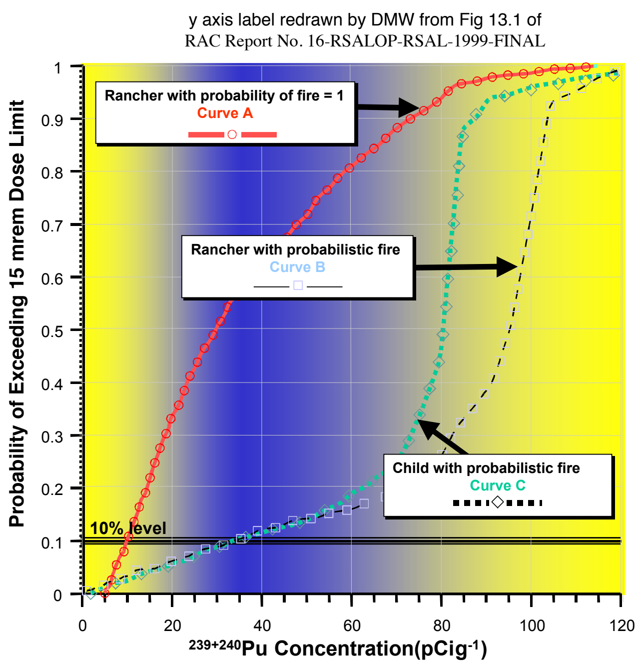

Figure 3: Fig. 13.1 from [2]

prepared before the target level of 50 picocuries per gram of $^{239+240}$Pu for mitigated soil had been agreed upon. The 'probabilistic' fire curve reflects the estimated probability of exceeding the nominal yearly dose of 15 mrem using the estimated most likely parameters of a fire within Rocky Flats. As an example: at the 50 pCi/gram soil concentration target, the probability of exceeding the nominal dose is about 15%. Also worth noting is that the highest *measured* soil concentration within the Refuge is [3] about 20 picocuries per gram (pCi/g) of soil.

The points above are made to show that the possibility of some Pu redistribution due to fires should be taken seriously, but also that they have been very carefully considered *already*. This means that postponing *prescribed burns* by the Fish & Wildlife Service is a disservice to those who live around the Rocky Flats National Wildlife Refuge and a waste of F&W resources and

Nonetheless, I will touch briefly on some of the issues determining how much radiation would be redistributed as the result of a fire on the Rocky Flats prairie are. Two obvious questions are (i) the extent to which Pu and Am are concentrated in above-ground parts of grasses and other vegetation, so that when burned they may be redeposited elsewhere, and (ii) how far ash from such fires would be blown. This in turn depends on the size distribution of ash particles. [Remember that 'hot particle' scenarios are no longer taken seriously as a special form of exposure.]

1. Pu on Rocky Flats is almost entirely in the relatively insoluble PuO_2 form. In the 1979 report [4] *Plutonium-239 and Americium241 uptake from plants from soil* available from the EPA, K. W. Brown describes laboratory (greenhouse) experiments with a variety of plants:

   - The 'concentration ratio'

     $$CR = \text{conc Pu in dry plant}/\text{conc Pu in dry soil},$$

     where concentrations were measured in nanocuries per gram, was measured to be $(2.5 \pm 1.5) \times 10^{-6}$. This means that ^{239}Pu is actually segregated by the plants measured—only about 1 Pu atom in 400,000 makes it from the soil into the plant. The author terms this 'large discrimination against plutonium absorption by plants'.

   - "...plutonium in the form of plutonium-239 dioxide is taken up and translocated to the aerial portions of the commonly cultivated plant species, alfalfa. Based on the concentration ratios, the amount of plutonium assimilated and translocated by this plant

Translocation = movement of materials from leaves to other tissues throughout a plant; in this case, from the roots (which presumably absorb some Pu from the soil) to leaves.

species appears to be in about the same proportion as the incorporation of other chemical forms of plutonium by a variety of other plants, including both aquatic and terrestrial species." [4] Similarly, "Americium in the form of $^{241}\text{Am}(NO_3)_3$ was also shown to be taken up and translocated to the aerial organs of five species of commonly cultivated crop and pastureland plants. The amount of americium assimilated and translocated by these plant species appeared to be similar in magnitude to that assimilated by other plant species under a variety of conditions."

- It is worth noting that concentration ratios for ^{241}Am in the five plant species measured were about one hundred times larger than for ^{239}Pu.
- "The long-term exposure of the alfalfa did not cause any increase in the concentration of plutonium in the plant tissue, even though the root mass increased." Similarly, "The long-term exposure of these species did show an increase in the concentration of americium in the plant tissues."

Later work was carried out by F. W. Whicker specifically at the behest of the Rocky Flats Citizen's Advisory Board, and reported in the document *Plant transfer factors for plutonium and americium at Rocky Flats: a review and analysis* on work done from 1982-1995. In the context of the use of the residual radiation exposure tool RESRAD (discussed in more detail in the document From radiation dose to cancer risk, the quantities described as concentration factors above are known as *transfer factors*. I am guessing that this work—which focused on vegetables in a hypothetical vegetable garden—was undertaken for a possible 'subsistence farmer' scenario, which did not end up being used for the Rocky Flats cleanup.

2. There is a large literature on fire severity and its impact on soils after fires. There is evidence that *controlled* burns result in *larger* ash particles than do wildfire

burns: "The lower temperatures in prescribed and low severity fires result in larger particle sizes, and within a specific fire there are differences in size according to the ash combustion completeness."[5].

A project for a college class

It is not clear that the Fish&Wildlife Service would be (or should be) enthusiastic about additional measurements on a site already repeatedly very well characterized and classified as appropriate for unlimited use by people. Nonetheless, in the absence of direct and recent measurements on Pu uptake by vegetation, a simple procedure (under the supervision of a college faculty member with access to a gamma-ray spectrometer) could allay many fears about controlled burns:

1. Identify a 10 meter square area of vegetation regarded as fairly typical of the area likely to burn or to be burned in a controlled way.
2. Scythe down all above-ground vegetation in this area. (If desired, wear paper face masks to avoid dust.) Save vegetation in sealed plastic garbage bags.
3. Allow vegetation to dry and compact.
4. Dissolve all vegetation in concentrated nitric or other acid identified as more appropriate. (Again, wear face mask if desired.) Save the fluid and discard the plastic garbage bags.
5. Count the fluid sample (or some appropriate smaller volume) in a calibrated γ-ray detector or spectrometer to identify the net Pu activity (per $100\,m^2$).
6. Repeat using a characteristic Am gamma peak if ^{241}Am activity is desired.
7. Dispose of sample appropriately (typically simply by dilution). Because of the extremely low levels of potential radiation, it is exempt from special handling requirements.

This provides a straightforward means of plausibly identifying the release of Pu during a controlled (or uncontrolled) burn of grassland within the Wildlife Refuge.

Takeaway messages

- The significance of animal burrowing is probably negligible, since the fraction of *wildlife refuge* area occupied by animal burrows is very small–probably under 0.1%.
- Careful research above indicates that very little Pu is taken up by vegetation in any case–concentrations hugely below what is in the soil itself.
- There is some evidence that the lower temperatures of controlled burns result in larger ash particles which are less likely to be spread by the wind.
- Under no circumstances anywhere would a wildfire be preferable to a controlled burn; this certainly holds in the RF Wildlife Refuge.

References

[1] W. F. Andelt and S. N. Hopper. *Managing Prairie Dogs - 6.506 - ExtensionExtension*. 2016. URL: http://extension.colostate.edu/topic-areas/natural-resources/managing-prairie-dogs-6-506/ (visited on 03/05/2018).

[2] John E Till. *Final Report: Task 5: Independent Calculation*. Tech. rep. 2000. URL: http://rockyflatssc.org/rfcab_projects/rsal_task5.pdf.

[3] Colorado Department of Public Health & Environment. *What are the risks to a Rocky Flats National Wildlife Refuge visitor? | Department of Public Health and Environment*. URL: https://www.colorado.gov/pacific/cdphe/rocky-flats-risks-to-refuge-visitor (visited on 01/14/2018).

[4] Kenneth W Brown. *Plutonium-239 and Americium-241 uptake by plants from soil*. Tech. rep. 1979. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/9101AEK6.PDF?Dockey=9101AEK6.PDF.

[5] Merche B. Bodí et al. “Wildland fire ash: Production, composition and eco-hydro-geomorphic effects”. In: *Earth-Science Reviews* 130 (2014), pp. 103–127. ISSN: 00128252. DOI: 10.1016/j.earscirev.2013.12.007. URL: http://dx.doi.org/10.1016/j.earscirev.2013.12.007.

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